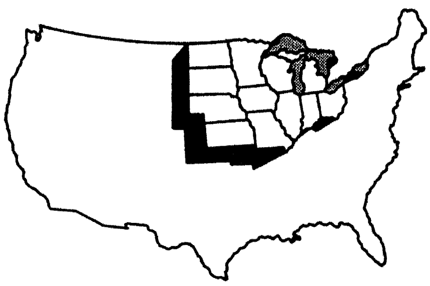
North Central Regional Research Publication 268
September 1980

Nutrient Content of Tile Drainage from Cropland in the North Central Region

TERRY J. LOGAN, GYLES W. RANDALL, and DON R. TIMMONS



Agricultural Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin, and the U. S. Department of Agriculture cooperating.

OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
WOOSTER, OHIO RESEARCH BULLETIN 1119

CONTENTS

*** ***

LIST OF TABLES

LIST OF FIGURES

AGDEX 531-750

9-80-3M

FOREWORD

Sponsored by the Agricultural Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin, and by the U. S. Department of Agriculture, Science and Education Administration—Agricultural Research.

This publication was prepared by the North Central Regional Committee, NC-98, Environmental Accumulation of Nutrients as Affected by Soil and Crop Management. Members of that committee have included:

State Agricultural Experiment Stations

F. J. Woodling ---------- Alaska
L. F. Welch, L. T. Kurtz ---------- Illinois
D. W. Nelson ---------- Indiana
M. A. Tabatabai ---------- Iowa
L. F. Murphy, D. Kissel ---------- Kansas
B. G. Ellis ---------- Michigan
G. W. Randall, R. G. Gast ---------- Minnesota
R. W. Blanchard, G. W. Colliver ---------- Missouri
R. A. Olson ---------- Nebraska
J. W. Bauder, J. Moraghan, K. Cassel ---------- North Dakota
T. J. Logan ---------- Ohio
E. M. White ---------- South Dakota
D. R. Keeney, R. Corey ---------- Wisconsin

U. S. Department of Agriculture

Science and Education Administration, Agricultural Research ---- R. E. Burwell, R. F. Holt, D. R. Timmons
Science and Education Administration, Cooperative Research ---- A. Newman, E. V. Miller
Forest Service ---------- S. Verry

Administrative Advisors

R. R. Davis ---------- Ohio
W. W. Sahs ---------- Nebraska

The publication was prepared by T. J. Logan, Ohio Agricultural Research and Development Center; G. W. Randall, University of Minnesota; and D. R. Timmons, USDA/SEA-AR. D. R. Timmons developed the standard reporting form and the data were compiled by T. J. Logan.

Data were contributed by T. J. Logan, G. W. Randall, and D. R. Timmons of the NC-98 Committee as well as by J. Laflen, Iowa State University, and G. O. Schwab, Ohio Agricultural Research and Development Center.

Nutrient Content of Tile Drainage from Cropland in the North Central Region

TERRY J. LOGAN, GYLES W. RANDALL, and DON R. TIMMONS

ABSTRACT

Tile drainage is a major practice on the millions of hectares of poorly drained cropland in the North Central Region, and nutrients in tile flow are a significant contribution to the total nutrient export from this area. Several studies at North Central Region institutions have monitored nutrients in tile drainage under varying soil, crop, and climatic conditions. This publication summarizes precipitation, tile flow, and nitrogen and phosphorus losses from tile drainage experiments in Iowa, Minnesota, and Ohio, and is intended for researchers and water quality management planners. Tile flows varied from 0 to 40 cm per year and reflected annual variations in precipitation for the most part, but also differences in soil physical properties and ET. Nitrate-N losses were generally < 30 kg N/ha but increased with nitrogen fertilizer applications in excess of crop needs. Nitrate losses with alfalfa were very low. Phosphorus losses from tile links were low, and much of the P losses were in a non-reactive form. Except where nitrogen in excess of crop requirements is applied, the quality of tile drainage water is usually better than runoff water, especially with respect to phosphorus.

INTRODUCTION

In recent years, there has been considerable research on the discharge of pollutants in drainage from agricultural land. In addition, Section 208 of the Water Quality Act, P. L. 92-500, requires that nonpoint sources of pollution be addressed in planning for water quality improvement. A number of field studies on nutrient and sediment losses from agricultural land have been conducted in the North Central Region, an area which represents a large percentage of the feed grain production in the U. S. and a region which accounts for much of the fertilizer application to U. S. cropland.

Many of the studies in this region have investigated the contribution of subsurface drainage (tile) to the discharge of nutrients and sediment to surface waters. Large acreages in the region are poorly drained and subsurface drainage is an extensive and growing practice in this area. While some of these studies have been published previously, several have not, and no attempt to date has been made to summarize the available data in a single report.

The objective of this regional publication is to provide researchers and planners with valid information on regional levels of nutrient losses in tile drainage from agricultural land.

The data summarized in this publication were contributed from studies in Iowa, Ohio, and Minnesota. In Iowa, data were provided by John Laflen and Ali Tabatabai; in Minnesota by Bob Gast, Wally Nelson, Gyles Randall, and Don Timmons; and in Ohio by Terry Logan and Glenn Schwab.

Until the 1960's, research on tile drainage was concerned with the hydraulic effectiveness of these systems, and studies on tile flow, soil hydraulic conductivity, and water table draw-down were common. However, concern in the last decade for agricultural water quality prompted studies on tile effluent composition. Many early studies reported nutrient concentrations only (7), but more recent studies have attempted to measure tile flow in conjunction with water quality analysis to determine losses. Baker and Johnson (1) summarized many of these studies. Of the approximately 20 studies, only six reported tile flow, which ranged from 7.0 cm/yr in Ontario, Canada, with a corn-oats-alfalfa-bluegrass rotation, to 39.1 cm/yr in Georgia with corn. Nitrate-N concentrations ranged from 0.6 μg/ml with a hay-pasture system to 32 μg/ml with soybeans. Soluble phosphate concentrations ranged from 0.0004 μgP/ml with soybeans to 0.36 μgP/ml with citrus in Florida.

Studies by Bolton *et al.* (3), Zwerman *et al.* (9), and Gast *et al.* (4) showed that increased fertilizer rates resulted in increased nutrient losses in tile, while Schertz and Miller (6), Olsen *et al.* (5), and Bolton *et al.* (3) found higher nutrient losses with corn as compared to alfalfa or bluegrass sod. Most studies indicated that much higher losses of NO_3-N are found as compared to phosphate. Schwab *et al.* (7) reported significant amounts of sediment in tile under a high-clay soil which contributed most of the total P losses they reported.

The literature indicates that losses of nutrients in tile drainage are related to flow, which in turn is related to climatic factors such as precipitation and ET, and soil factors such as infiltration, hydraulic conductivity, slope, and texture. The literature also shows that crop nutrient requirements and ability of crops to remove nutrients from solution will affect tile drainage losses. Fertilizer application rates, especially nitrogen, are also related to tile effluent concentrations and losses.

Although this report only presents data for nutrients lost in tile drainage, it is important to place these data in the context of total nutrient losses from a field or watershed. Because of the strong affinity of soil for soluble phosphate, tile drainage rarely contains more than trace quantities of soluble P and much of its P load from tile drainage is contributed by P attached to fine clay particles or organic colloids. In contrast, surface runoff contains not only soluble P but also phosphate absorbed to, or part of, the eroded soil particle, and the total P load from surface runoff is usually much greater than that from tile drainage.

On the other hand, nitrate is not retained by soil particles, and because of its high water solubility, will move freely with either surface runoff or tile drainage; tile drainage usually has higher NO_3-N concentrations than surface runoff, and usually accounts for most of the load.

Surface runoff and tile drainage will also contain low concentrations of NH_4-N (< 1.0 μg N/ml), and since NH_4^+ is retained on the cation exchange capacity of soil colloids, NH_4-N concentrations in tile drainage are generally < 0.5 μg N/ml and were not included in this report.

PROCEDURES

The NC-98 committee developed a standard reporting form for tile drainage data which was then circulated to each state representative. Data were received from Iowa, Minnesota, and Ohio and were compiled for each state and summarized for the region. Sufficient information to describe the tile system, monitoring procedures, crops, soil types, fertilization programs, and period monitored was provided as well as data on annual precipitation, tile flow, and nutrient losses. Some of the data have been published previously as individual journal articles or project reports, and these are cited in the text where applicable so readers can obtain more detail than given here.

The sites included in this report are identified in Figure 1. Tables 1 and 2 in the discussion section summarize flow and nutrient losses for the entire region.

Appendices A, B, and C give the data for each system as reported on the standard form with a summary for each state (Tables 3, 4, and 5).

DISCUSSION

The tile drainage data presented here represent conditions that are quite typical of those found throughout the Corn Belt. The soils were all of glacial origin and range in texture from silt loam to clay, with clay loam most prevalent. Crops included corn, soybeans, oats, alfalfa, sorghum, and wheat, with corn represented either singly or in rotation.

The Iowa and Ohio sites fall between the 76.2 and 101.6 cm isoprecipitation lines (8), with the two Minnesota sites between 50.8 and 76.2 cm (Fig. 1). Precipitation above evaporation is about 25 cm for much of this area (8), and with runoff usually < 10 cm on the more level soils requiring tile drainage, tile

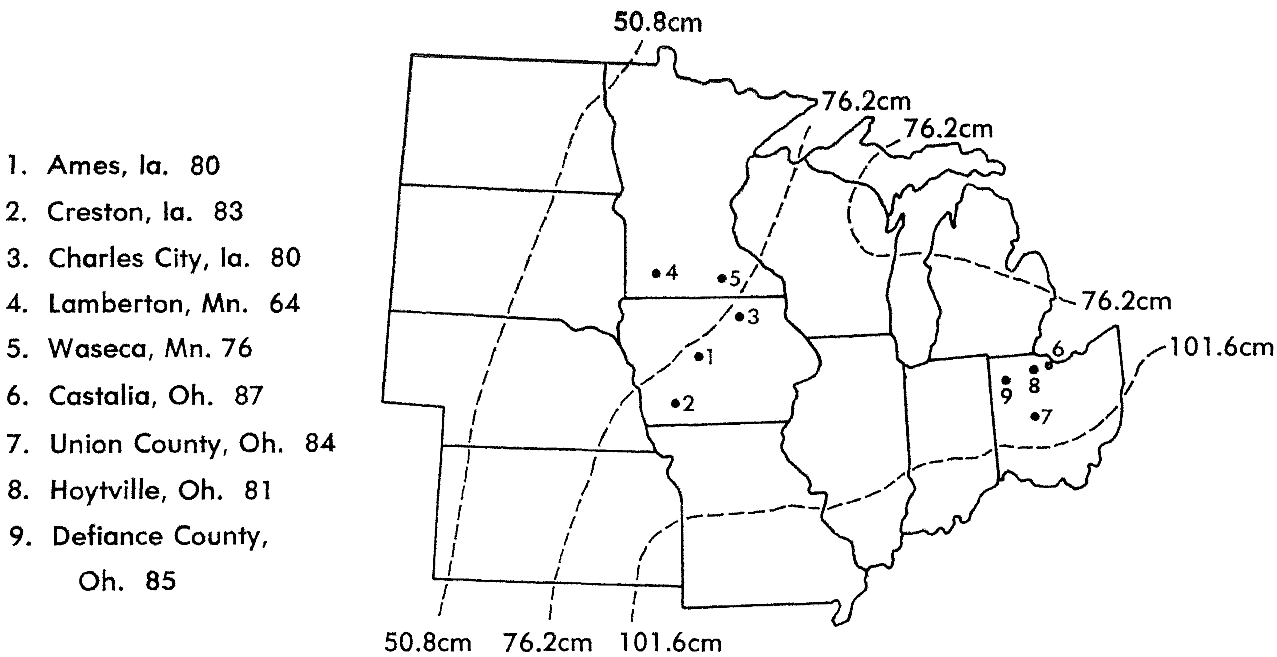


FIG. 1.—Location of tile drainage study sites in Iowa, Minnesota, and Ohio. Long-term rainfall is given as annual isoprecipitation lines (8). Mean annual precipitation is shown at right of each site's name.

TABLE 1.—Summary of Precipitation and Tile Flow from Systems in Iowa, Minnesota, and Ohio.

Soil Type	Crop	Year	Precipitation	Flow	Percentage of Precipitation as Flow
			cm		
		IOWA			
Clarion-Webster silt loam	corn-oats-corn-soybeans	mean of 1970-73	92.8	14.6	15.7
Sharpsburg silty clay loam	corn and soybeans	mean of 1970-72	73.7	2.82	3.8
Floyd loam	corn	mean of 1970-72	65.0	11.8	18.2
		MINNESOTA			
Nicollet and	corn	1969	60.9	13.45	22.1
Webster clay loam	small grain, flax, sorghum, soybeans		60.9	7.08	11.6
Nicollet and	50% corn,	1973	103	41.1	39.9
Webster clay loam	50% soybeans	1974	65	21.3	32.8
		1975	73	23.9	32.7
Nicollet and	45% corn,	1973	103	20.3	19.7
Webster clay loam	40% soybeans,	1974	65	11.9	18.3
	and 15% oats	1975	73	13.0	17.8
Webster clay	corn	1973	52	3.7	7.1
loam (Lamberton)		1974	46	9.1	19.8
		1975	59	12.8	21.7
		1976 (drought)	32	0.0	0.0
		1977	86	1.4	1.6
		1978	52	5.0	9.6
Webster clay	corn	1976	44.3	0.0	0.0
loam (Waseca)		1977	104.5	12.3	11.7
		1978	78.4	14.2	18.2
		OHIO			
Toledo and Fulton clays	corn-oats	1969	106.2	35.3	33.2
		1970	81.8	12.3	15.0
		1971	68.8	9.5	13.8
50% Crosby silt loam	corn	1972	34.3*	21.8	63.6
and 50% Brookston silty clay loam		1973	49.3*	32.5	65.9
75% Blount silt loam,	corn	1972	19.8*	9.1	46.0
25% Morley silt loam		1973	29.0*	14.7	50.7
	alfalfa	1972	18.8*	1.5	8.0
		1973	34.0*	8.1	23.8
Hoytville clay	soybeans	1975	79.4†	24.3†	30.6
		1976	67.9	22.8	33.6
		1977	94.4	25.7	27.2
Blount loam	soybeans	1975	43.8‡	5.8‡	13.2
		1976	66.1	11.5	17.4
		1977	34.5**	9.3**	27.0
Paulding clay	soybeans	1975	52.1‡	0.9‡	1.7
		1976	61.5	2.8	4.6
		1977	35.8**	0.0**	0.0
Lenawee sandy clay loam	soybeans	1975	42.6‡	10.2‡	23.9
		1976	59.2	9.0	15.2
		1977	32.1**	7.0**	21.8

*Represents precipitation only for the period of tile flow, usually February through May.
†Monitoring began in April 1975.
‡Monitoring began in July 1975.
**Monitoring terminated at the end of May 1977.

flow would be expected to be ~ 15 cm. A summary of rainfall and tile flow for all systems is given in Table 1. All individual system data are given in the appendices.

Seasonal variation in precipitation was evident in all areas, and precipitation and crop growth (ET) were the governing factors in determining tile flow. Soil structure and internal drainage differences were also apparent. Hoytville and Paulding soils in Ohio have similar textures, but the weakly expressed structure of Paulding clay gave much lower tile flow volumes than Hoytville under similar rainfall conditions. The alfalfa crop in Ohio with its deeper root system gave lower tile volume than corn on similar soils and similar climatic conditions. The Iowa systems had mean precipitation of 77.2 cm and tile flow of 9.7 cm (tile flow was 12.6% of precipitation), with tile flow more variable than precipitation. The Minnesota data had a precipitation mean of 65.8 cm and tile flow of 12.4 cm. In Ohio, precipitation averaged 75.7 cm and tile flow was 16.9 cm. Year-to-year variation in precipitation and tile flow appears to be greater than among states.

The relationship between precipitation and tile flow was examined by plotting normalized precipitation vs. normalized tile flow for those sites which had at least 2 complete years' data and measurable tile flow (Fig. 2). Precipitation and flow were normalized by dividing each year's precipitation by the lowest annual precipitation for each study. Flow was then normalized by dividing the flow for the year with lowest precipitation into the flows for the other years. Figure 2 shows that when the data are normalized to remove regional soil and precipitation differences, there is a clear linear relationship between tile flow and precipitation. An exception to this was the data for the Webster clay loam soil in Minnesota where the lowest precipitation did not produce the lowest tile flow. This analysis obviously does not consider the effect of rainfall distribution on tile flow. Precipitation in the summer produces little tile flow because of high ET, and winter precipitation may not infiltrate on frozen soil. However, Figure 2 does demonstrate that precipitation is the major factor affecting tile flow and may be used as a first approximation of tile flow where no other data are available.

The nutrient loss parameters varied from study to study, but in all cases NO_3-N was determined, and ortho-P (includes data reported as dissolved or filtered inorganic P) and total P were determined in most cases. Table 2 summarizes the nutrient loss data for NO_3-N, ortho-P, and total P. Data for other parameters can be found in the appendices. Nitrogen losses were highest on nitrogen-fertilized corn, were intermediate for soybeans or systems where other crops were in the rotation, and were lowest for alfalfa. This is especially evident when NO_3-N concentrations are examined. Nitrate-N concentrations were above 10 μg/ml even when 20 kg N/ha or less was applied annually to corn (Appendix B). Nitrogen losses were especially high when higher than recommended rates of fertilized N were applied. The effect of continued N application through very dry years when crop uptake was minimal resulting in N buildup can be seen by the high N losses in succeeding years when tiles flowed (Minnesota).

The higher ortho-P and total P losses from the Ohio soils (Table 2) appear to be primarily due to the finer texture of these soils compared with those from Iowa or Minnesota (Table 1). The clay fraction of soil contains higher concentrations of phosphate than coarser (silt and sand) fractions.

LITERATURE CITED

1. Baker, J. L. and H. P. Johnson. 1977. Impact of subsurface drainage on water quality. 3rd National Drainage Symp. ASAE, Chicago, Ill.
2. Baker, J. L., J. L. Laflen, H. P. Johnson, and J. J. Hanway. 1975. Nitrate, phosphorus and sulfate in subsurface drainage water. J. Environ. Qual., 4:406-412.
3. Bolton, E. F., J. W. Aylesworth, and R. F. Hore. 1970. Nutrient losses through tile drains under three cropping systems and two fertility levels on a Brookston clay soil. Can. J. Soil Sci., 50: 275-279.
4. Gast, R. G., W. W. Nelson, and G. D. Randall. 1978. Nitrate accumulation in soils and loss in tile drainage following nitrogen applications in continuous corn. J. Environ. Qual., 7:258-261.
5. Olsen, R. J., R. F. Hensler, O. J. Attoe, S. A. Witzel, and L. A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Sci. Soc. Amer. Proc., 34:448-452.
6. Schertz, D. L. and D. A. Miller. 1972. Nitrate-N accumulation in the soil profile under alfalfa. Agron. J., 64:660-664.
7. Schwab, G. O., E. O. McLean, A. C. Waldron, R. K. White, and D. W. Michener. 1973. Quality of drainage water from a heavy-textured soil. Trans. ASAE, 16:1104-1107.
8. Visher, S. S. 1954. Climatic Atlas of the United States. Harvard University Press, Cambridge, Mass. 403 pp.
9. Zwerman, P. J., T. Greweling, S. D. Klausner, and D. J. Lathwell. 1972. Nitrogen and phosphorus content of water from tile drains at two levels of management and fertilization. Soil Sci. Soc. Amer. Proc., 36:134-137.

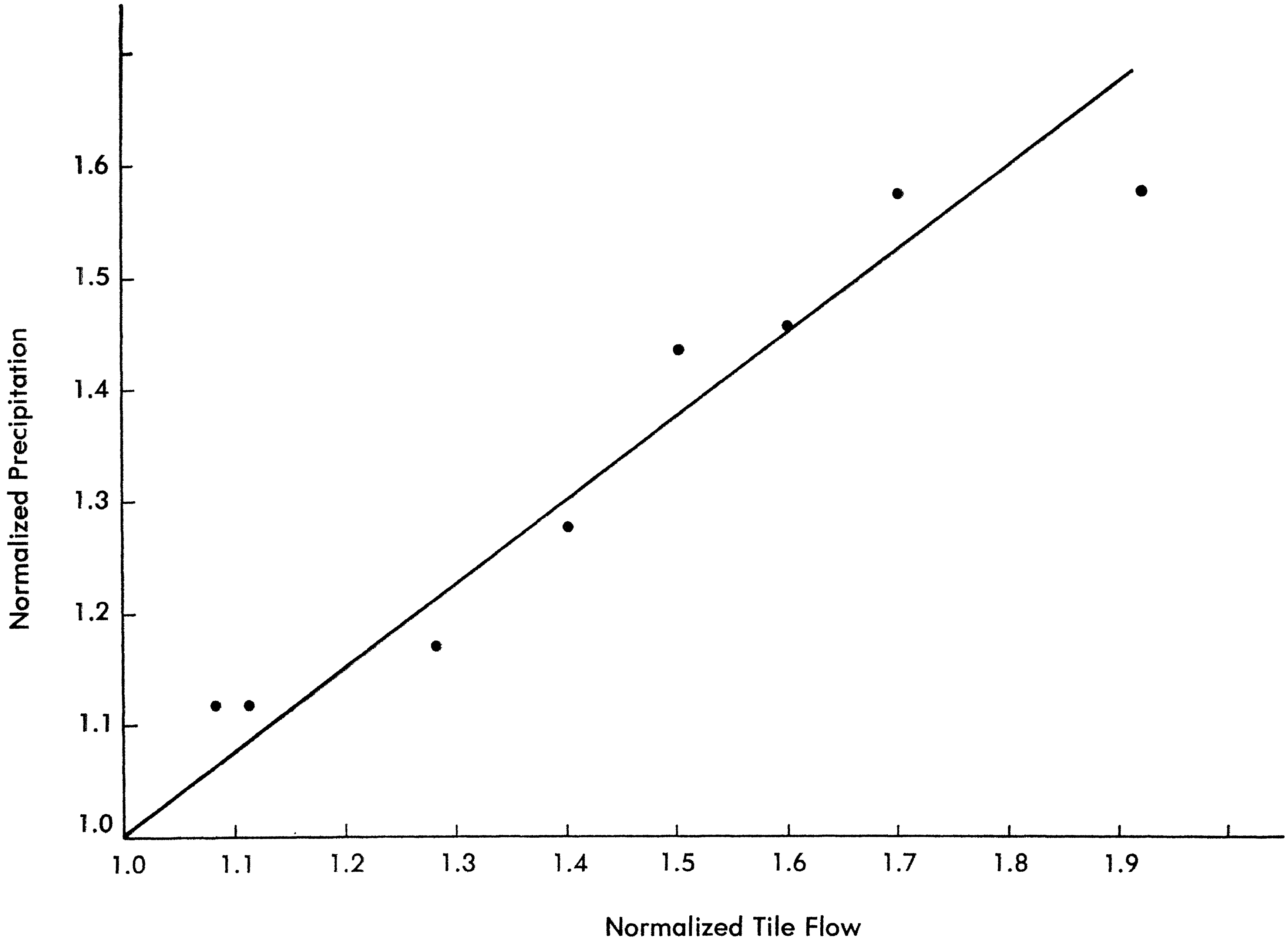


FIG. 2.—The linear relationship between site-normalized precipitation and tile flow for sites with more than 1 year of data.

TABLE 2.—Summary of Nutrient Losses in Tile Drainage in Iowa, Minnesota, and Ohio.

Site	Crop	Treatment	Year	Flow	NO_3-N	Ortho-P	Total P	NO_3-N	Ortho-P	Total P
				cm	kg/ha			µg/ml*		
									X 10^2	
		IOWA								
Plots	corn-oats-corn-soybeans	112 kgN/ha on corn		14.6	30.6	0.003	0.018	21.0	0.2	1.23
Creston	corn-soybeans	105 kgN/ha on corn		2.8	2.1		0.020	7.5		7.14
Charles City	corn	221 kgN/ha		11.8	20.5		0.040	17.4		3.39
		MINNESOTA								
Small System	small grain, flax, sorghum, soybeans	95 kgN/ha	1969	7.08	12.1	0.04	0.10	17.1	5.6	14.1
Small System	corn	112 kgN/ha	1969	13.45	18.3	0.09	0.20	13.6	6.7	14.9
Large System	50% corn	220 kgN/ha on corn	1973	20.3	54.0	0.02	0.04	26.6	1.0	2.0
	50% soybeans		1974	11.9	31.0	0.03		26.1	2.5	
			1975	13.0	46.0	0.01		35.4	0.8	
Large System	45% corn	190 kgN/ha on corn	1973	41.1	108.0	0.16	0.09	26.3	3.9	2.2
	40% soybeans		1974	21.3	59.0	0.08		27.7	3.8	
	15% oats		1975	23.9	82.0	0.12		34.3	5.0	
Tile Plots—1	corn	20 kgN/ha	1973†	3.7	5.0			13.5		
			1974	9.1	17.0			18.7		
			1975	12.8	19.0			14.8		
			1976	0.0	0.0					
			1977	1.4	4.9			35.0		
			1978	5.0	11.6			23.2		
	corn	112 kgN/ha	1973†	3.7	6.0			16.2		
			1974	9.1	22.0			24.2		
			1975	12.8	25.0			19.5		
			1976	0.0	0.0					
			1977	1.4	6.7			47.9		
			1978	5.0	28.9			57.8		
	corn	224 kgN/ha	1973†	3.7	4.0			10.8		
			1974	9.1	30.0			33.0		
			1975	12.8	59.0			46.1		
			1976	0.0	0.0					
			1977	1.4	7.3			52.1		
			1978	5.0	48.5			97.0		
	corn	448 kgN/ha	1973†	3.7	6.0			16.2		
			1974	9.1	54.0			59.3		
			1975	12.8	120.0			93.8		
			1976	0.0	0.0					
			1977	1.4	19.7			140.7		
			1978	5.0	97.8			195.6		

*Flow weighted mean annual concentrations. kg/ha-cm=0.1 mg/ml.
†First year of study. N applied in May and tile flowed from April 10 through June 15. Previous crop was corn with no fertilizer N added for 13 years.

TABLE 2 (Continued).—Summary of Nutrient Losses in Tile Drainage in Iowa, Minnesota, and Ohio.

Site	Crop	Treatment	Year	Flow	NO_3-N	Ortho-P	Total P	NO_3-N	Ortho-P	Total P
				cm	kg/ha			µg/ml*		
									X 10^2	
		MINNESOTA (Continued)								
Tile Plots—2	corn	0 kgN/ha	1976	0.0						
			1977	12.3	14			11.4		
			1978	14.2	18			12.7		
	corn	112 kgN/ha	1976	0.0						
			1977	12.3	33			26.8		
			1978	14.2	29			20.4		
	corn	224 kgN/ha	1976	0.0						
			1977	12.3	41			33.3		
			1978	14.2	56			39.4		
	corn	336 kgN/ha	1976	0.0						
			1977	12.3	82			66.7		
			1978	14.2	107			75.4		
		OHIO								
Castalia	corn-oats	no-till	1969	33.1	32.3	1.27		9.8	38.4	
		224 kgN/ha on corn	1970	9.0	28.6	0.58	0.74	31.8	64.4	82.2
			1971	10.2	10.7	0.29	0.78	10.5	28.4	76.5
		fall plow	1969	37.5	31.2	1.37		8.3	36.5	
		224 kgN/ha on corn	1970	16.0	25.5	0.19	0.80	15.9	11.9	50.0
			1971	8.8	18.9	0.07	0.40	21.5	8.0	45.5
Dellinger Farm	corn	22 kgN/ha in 1972;	1972	21.8	36.5	0.46		16.7	21.1	
		224 kgN/ha in 1973	1973	32.5	45.6	0.20		14.0	6.2	
Durban Farm	corn	59 kgN/ha in 1972;	1972	9.1	11.4	0.41		12.5	45.1	
		258 kgN/ha in 1973	1973	14.7	30.8	0.20		21.0	13.6	
Wedding Farm	alfalfa	∼20 mt/ha of dairy manure	1972	1.5	0.1	0.006		0.7	4.0	
			1973	8.1	1.3	0.13		1.6	16.0	
Hoytville Plots	soybeans		1975	24.3	17.1	0.03	0.12	7.1	1.2	5.0
			1976	22.8	11.9	0.10	0.45	5.2	4.4	19.6
			1977	25.7	23.0	0.26	0.82	9.0	10.0	31.8
Heisler Farm	soybeans		1975	5.8	7.2	0.03	0.10	12.3	5.2	17.4
			1976	11.5	9.6	0.09	0.39	8.4	7.8	34.0
			1977	9.3	11.3	0.03	0.31	12.2	3.2	33.7
Speiser Farm	soybeans		1975	0.9	0.4	0.01	0.12	4.9	11.1	136.9
			1976	2.8	9.2	0.01	0.09	32.8	3.6	32.0
			1977	0.0						
Rohrs Farm	soybeans		1975	10.2	10.9	0.04	0.94	10.6	3.9	92.3
			1976	9.0	5.7	0.08	0.27	6.4	8.7	29.9
			1977	7.0	8.4	0.09	0.49	12.0	12.8	38.4

*Flow weighted mean annual concentrations. kg/ha-cm=0.1 mg/ml.
†First year of study. N applied in May and tile flowed from April 10 through June 15. Previous crop was corn with no fertilizer N added for 13 years.

APPENDIX A
IOWA

Three experiments are included: 1) Four plots, each 0.4 ha, at the Iowa State Agricultural Research Center, Ames. 2) A tiled terrace system, 3.2 ha, near Creston. 3) A tiled terrace system, 9.2 ha, near Charles City. The two tile terrace systems have been previously reported by Hanway and Laflen (4) and the plots by Baker *et al.* (2).

1. PLOT STUDY

Site Characteristics

Location: Agricultural Research Center, Iowa State Univ., Ames
Area: four plots, each 0.4 ha
Soil: Clarion-Webster silt loam

Tile Characteristics and Monitoring

Tile depth (meters): 1.2
Tile spacing (meters): 37
Tile flow frequency: intermittent; spring and fall
Sampling method: both automatic sampler and grab sample
Sampling frequency: daily
Years sampled: 1970-1973

Crop Production Characteristics

Crops: corn-oats-corn-soybeans
Fertilizer: 112 kg/ha urea applied to corn crop; broadcast in the spring
Tillage: conventional

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation			92.8	80.3
Tile Flow			14.6 (15.7 %)*	

*Percent of annual precipitation

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)
NH_4-N	—
NO_3-N	30.6
TKN	—
Ortho-P	0.003
Total P	0.018
K	—
SO_4-S	15.4

2. TERRACE—CRESTON

Site Characteristics

Location: Creston
Area: 3.2 ha terrace
Soil: Sharpsburg silty clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 1-1.1
Tile spacing (meters): 38
Tile flow frequency: intermittent
Sampling method: automatic sampler
Sampling frequency: continuous
Years sampled: 1970-1972; April-November

Crop Production Characteristics

Crops: corn and soybeans
Fertilizer: 105 kg/ha as NH_3; 38 kgP_2O_5/ha and 17 kgK_2O/ha as fall plow down
Tillage: conventional

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation			73.69	83.2
Tile Flow			2.82 (3.8 %)	

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)
NH_4-N	—
NO_3-N	2.1
TKN	—
Ortho-P	—
Total P	0.02
K	—
SO_4-S	2.8

3. TERRACE—CHARLES CITY

Site Characteristics

Location: Charles City
Area: 9.2 ha terrace
Soil: Floyd loam

Tile Characteristics and Monitoring

Tile depth (meters): 1-1.1
Tile spacing (meters): 63
Tile flow frequency: intermittent (April-July)
Sampling method: automatic sampler
Years sampled: 1970-72; April-November

Crop Production Characteristics

Crop: corn
Fertilizer: 221 kgN/ha as NH_3 in spring; 100 kgP_2O_5/ha and 101 kgK_2O/ha plowed down in fall
Tillage: conventional

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation			65	80.3
Tile Flow			11.8 (18.2 %)	

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)
NH_4-N	—
NO_3-N	20.5
TKN	—
Ortho-P	—
Total P	0.04
K	—
SO_4-S	16

TABLE 3.—Summary of Iowa Tile Drainage Data

Site	Area	Precipitation	Flow	NO_3-N	Ortho-P	Total P	SO_4-S
	ha	cm		kg/ha/yr			
Plots	0.4	92.8	14.6	30.6	0.003	0.018	15.4
Creston	3.2	73.7	2.8	2.1		0.020	2.8
Charles City	9.2	65.0	11.8	20 5		0.040	16.0
Mean		77.2	9.7 (12.6)*	17.7	0.003	0.026	11.4

*Percentage of annual precipitation as tile flow.

APPENDIX B

MINNESOTA

Five experiments are included: 1) two small tile systems at Lamberton. 2) A 97-ha tile system at Waseca. 3) A 26-ha system at Waseca. 4) 12 plots at Lamberton with differential N application rates. 5) 12 plots at Waseca with differential N application rates.

1. TWO TILE SYSTEMS

Site Characteristics

Location: Southwest Experiment Station, Lamberton
Area: 2.2 ha and 0.93 ha (estimated)
Soil: Nicollet and Webster clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 1.2
Tile spacing (meters): 54 m for the 2.2 ha site; 27 m for the 0.93 ha site
Tile flow frequency: intermittent
Sampling method: grab samples; flow recorder
Sampling frequency: daily during April; weekly during May-July
Year sampled: 1969

Crop Production Characteristics

Crops: corn on the 2.2 ha system; the 0.93 ha area had small grain, flax, sorghum, and soybeans
Fertilizer: the 2.2 ha system received 112 kgN/ha, 20 kgP/ha, and 20 kgK/ha; the 0.93 ha system received 95, 27, and 26 kg/ha of N, P, and K, respectively
Tillage: conventional

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation			60.9	64
Tile Flow 2.2 ha system			13.45 (22.1%)	
Tile Flow 0.93 ha system			7.08 (11.6%)	

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)	
	2.2 ha System	0.93 ha System
NH_4-N	0.6	0.2
NO_3-N	18.3	12.1
TKN	0.9	0.3
Ortho-P	0.09	0.04
Total P	0.20	0.10
K (soluble)	2.4	1.1

2. LARGE WATERSHED—1

Site Characteristics

Location: 5 miles west of Waseca
Area: 97 ha
Soil: Nicollet and Webster clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 1.2
Tile spacing (meters): 30
Tile flow frequency: continuous
Sampling method: grab sample
Sampling frequency: periodic depending on flow rate
Years sampled: 1973-1975

Crop Production Characteristics

Crops: 1973: 50% corn, 50% soybeans; 1974: 85% corn, 15% soybeans; 1975: 95% corn, 5% soybeans
Fertilizer: only corn; 220, 39, and 112 kg/ha of N, P, and K, respectively; fall applied
Tillage: moldboard plow

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1973	17	86	103	76
1974	7	58	65	76
1975	12	61	73	76
Tile Flow				
1973			41.1 (39.9%)	
1974			21.3 (32.8%)	
1975			23.9 (32.7%)	

Mean Annual Nutrient Concentrations and Losses in Tile Flow

Year	NH_4-N	NO_3-N	Ortho-P	Total P	Chloride
			$\mu g/ml$		
1973	0.052	26	0.022	0.038	25
1974		22	0.036		26
1975		34	0.042		26
		Annual Nutrient Losses (kg/ha)			
1973	0.21	108	0.09	0.16	91
1974		59	0.08		43
1975		82	0.12		35

3. LARGE WATERSHED—2

Site Characteristics

Location: Southern Experiment Station, Waseca
Area: 26 ha
Soil: Nicollet and Webster clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 1.2
Tile spacing (meters): 23
Tile flow frequency: continuous during flow periods
Sampling method: grab sample
Sampling frequency: three times/mo and greater where needed
Years sampled: May-Dec 1973; Jan.-Aug 1974; April-July 1975; no flow from Aug 1974-March 1975

Crop Production Characteristics

Crops: 45% corn, 40% soybeans, 15% oats
Fertilizer: 190, 36, and 112 kg/ha of N, P, and K, respectively, on corn; 20 and 74 kg/ha of P and K, respectively, on soybeans and oats; broadcast in the fall
Tillage: moldboard plow

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1973	17	86	103	76
1974	7	58	65	76
1975	12	61	73	76
Tile Flow				
1973			20.3 (19.7%)	
1974			11.9 (18.3%)	
1975			13.0 (17.8%)	

Nutrient Concentrations and Losses in Tile Flow

Year	NH_4-N	NO_3-N	Ortho-P	Total P	Chloride
			μg/ml		
1973	0.017	28	0.010	0.024	40
1974		26	0.026		35
1975		35	0.006		35
		Annual Nutrient Losses (kg/ha)			
1973	0.03	54	0.02	0.04	77
1974		31	0.03		40
1975		46	0.01		46

4. TILE PLOTS—1

Site Characteristics

Location: Southwest Experiment Station, Lamberton
Area: 14 m x 15 m; 3 reps of each treatment
Soil: Webster clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 1.2
Tile spacing (meters): 28
Tile flow frequency: intermittent
Sampling method: grab sample
Sampling frequency: daily or every other day depending on flow
Years sampled: 1973-1978; sampled throughout the year

Crop Production Characteristics

Crop: corn
Fertilizer: 20, 112, 224, and 448 kgN/ha annual rates as urea; spring applied
Tillage: moldboard plow
Previous history: corn without added N for 13 years; in first year of the study (1973), N was applied in May while the tile lines flowed from April 10 through June 15

Precipitation and Tile Flow Characteristics

Year	Precipitation (cm)			
	Snow	Rain	Annual	Long-term
1973	9	43	52	64
1974	5	41	46	64
1975	14	45	59	64
1976	9	23	32	64
1977	17	69	86	64
1978	4	48	52	64

Year	Tile Flow (cm)	
	Annual	Percent of Annual Precipitation
1973	3.7	7.1
1974	9.1	19.8
1975	12.8	21.7
1976	0	
1977	1.4	1.6
1978	5.0	9.7

Nitrate-N Concentrations and Losses in Tile Flow

Year	Fert. N Rate (kg/ha)			
	20	112	224	448
		μg/ml		
1973*	13	15	13	12
1974	19	25	37	65
1975	19	23	43	81
1976				
1977	28	48	73	150
1978	21	53	119	191
		kg NO_3-N lost/ha		
1973*	5	6	4	6
1974	17	22	30	54
1975	19	25	59	120
1976	0	0	0	0
1977	5	7	7	20
1978	12	29	48	98

*First year of study after previously unfertilized corn.

5. TILE PLOTS—2

Site Characteristics

Location: Southern Experiment Station, Waseca
Area: 14 m x 15 m, 3 reps of each treatment
Soil: Webster clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 1.2
Tile spacing (meters): 28
Tile flow frequency: intermittent
Sampling method: grab sample
Sampling frequency: daily during flow periods
Years sampled: 1976-1978

Crop Production Characteristics

Crop: corn

Fertilizer: 0, 112, 224 and 336 kgN/ha as urea, usually in spring; nitrogen applications began in 1975; supplemental P and K broadcast each year

Tillage: moldboard plow

Previous history: continuous corn with approximately 170 kgN/ha annually

Precipitation and Tile Flow Characteristics

	Precipitation (cm)			
Year	Snow	Rain	Annual	Long-term
1976	6	38	44	76
1977	13	91	104	76
1978	10	68	78	76

	Tile Flow (cm)	
	Annual	Percent of Annual Precipitation
1976	0	
1977	12.3	11.7
1978	14.2	18.2

Nitrate-N Concentrations and Losses in Tile Flow

	Fert. N Rate (kg/ha)			
Year	0	112	224	336
		μg/ml		
1976*				
1977	13	41	58	85
1978	16	28	45	65
		kg NO_3-N lost/ha		
1976*				
1977	14	33	41	82
1978	18	29	56	107

*Dry year, very low crop yields.

TABLE 4.—Summary of Minnesota Tile Drainage Data.

Site	Area	Year	Precipitation	Flow	NO_3-N	Ortho-P	Total P
	ha		cm			kg/ha/yr	
Small System	0.93	1969	60.9	7.08	12.1	0.04	0.10
	2.2	1969	60.9	13.45	18.3	0.09	0.20
Large System	26	1973	103	20.3	54	0.02	0.04
		1974	65	11.9	31	0.03	
		1975	73	13.0	46	0.01	
Large System	97	1973	103	41.1	108	0.16	0.09
		1974	65	21.3	59	0.08	
		1975	73	23.9	82	0.12	
Plots—1	0.021	1973†	52	3.7	5		
		1974	46	9.1	17		
	20 kgN/ha	1975	59	12.8	19		
	(treatment)	1976	32	0	0		
		1977	86	1.4	5		
		1978	52	5.0	12		
		1973†	*	*	6		
		1974	*	*	22		
	112 kgN/ha	1975	*	*	25		
	(treatment)	1976	*	*	0		
		1977	*	*	7		
		1978	*	*	29		
		1973†	*	*	4		
		1974	*	*	30		
	224 kgN/ha	1975	*	*	59		
	(treatment)	1976	*	*	0		
		1977	*	*	7		
		1978	*	*	48		
		1973†	*	*	6		
		1974	*	*	54		
	448 kgN/ha	1975	*	*	120		
	(treatment)	1976	*	*	0		
		1977	*	*	20		
		1978	*	*	98		
Plots—2	0.021	1976	44	0.0			
	0 kgN/ha	1977	104	12.3	14		
	(treatment)	1978	78	14.2	18		
	112 kgN/ha	1976	*	*			
	(treatment)	1977	*	*	33		
		1978	*	*	29		
	224 kgN/ha	1976	*	*			
	(treatment)	1977	*	*	41		
		1978	*	*	56		
	336 kgN/ha	1976	*	*			
	(treatment)	1977	*	*	82		
		1978	*	*	107		
Mean			65.8	12.4			

*Same for all nitrogen rates within a study.
†First year of study. Previous crop was unfertilized corn.

APPENDIX C

OIHO

Eight experiments are included: 1) Plots at Castalia. 2) Plot on Dellinger Farm, Union County. 3) Plot on Durban Farm, Union County. 4) Plot on Wedding Farm, Union County. 5) Plots at Hoytville. 6) Plot on Heisler Farm, Defiance County. 7) Plot on Speiser Farm, Defiance County. 8) Plot on Rohrs Farm, Defiance County.

1. PLOTS AT CASTALIA

Site Characteristics

Location: North Central Branch, OARDC, Castalia
Area: 2 plots, each 0.074 ha
Soil: Toledo and Fulton silty clays

Tile Characteristics and Monitoring

Tile depth (meters): 0.91
Tile spacing (meters): 12
Tile flow frequency: intermittent
Sampling method: automatic sampler
Sampling frequency: continuous throughout the year
Years sampled: 1969-1971

Crop Production Characteristics

Crops: corn and oats rotation
Fertilizer: 224, 33 and 55 kg/ha, N, P and K, respectively, on corn only; applied in spring; N broadcast and P and K applied in row
Tillage: no-till and fall moldboard plow were variables on the two plots

Precipitation and Tile Flow (cm)

		Snow	Rain	Annual	Long-term
Precipitation	1969			106.2	86.6
	1970			81.8	
	1971			68.8	
Tile Flow					
No-till	1969			33.1*	
	1970			9.0	
	1971			10.2	
Fall Plow	1969			37.5*	
	1970			16.0	
	1971			8.8	

*There was a July 1969 storm of 29.5 cm which accounted for much of the tile flow that year.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)			
	NO_3-N	Ortho-P	Total P	Soluble K
No-till				
1969	32.3	1.27		6.12
1970	28.6	0.58	0.74	5.50
1971	10.7	0.29	0.78	3.29
Fall Plow				
1969	31.2	1.37		4.13
1970	25.5	0.19	0.80	4.74
1971	18.9	0.07	0.40	0.92

2. DELLINGER FARM

Site Characteristics

Location: Union County
Area: 2.9 ha
Soil: 50% Crosby silt loam, 50% Brookston silty clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 0.91
Tile spacing (meters): 16.7
Tile flow frequency: intermittent
Sampling method: grab sample
Sampling frequency: daily during April-July 1972 and March-August 1973
Years sampled: 1972-1973

Crop Production Characteristics

Crop: corn
Fertilizer: 1972: 22 and 55 kg/ha of N and K, respectively, in the row at planting; 1973: 224 kg/ha N broadcast at planting
Tillage: moldboard plow in spring

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1972			34.3*	84.4
1973			49.3*	84.4
Tile Flow				
1972			21.8 (63.6%)	
1973			32.5 (65.9%)	

*Only includes precipitation in April-July and March-August tile flow periods for 1972 and 1973, respectively.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha) 1972	1973
NO_3-N	36.5	45.6
Ortho-P	0.46	0.20
Soluble K	1.41	2.21

3. DURBAN FARM

Site Characteristics

Location: Union County
Area: 3.0 ha
Soil: 75% Blount silt loam and 25% Morley silt loam

Tile Characteristics and Monitoring

Tile depth (meters): 0.9
Tile spacing (meters): 16.7
Tile flow frequency: intermittent
Sampling method: grab sample
Sampling frequency: daily during April-May 1972 and March-July 1973
Years sampled: 1972-1973

Crop Production Characteristics

Crop: corn
Fertilizer: 1972; 59, 112 and 224 kg/ha of N, P and K, respectively, applied at planting; 1973: 45, 77 and 34 kg/ha of N, P and K, respectively, applied in row at planting; 168 kg/ha N broadcast at planting and 45 kg/ha N sidedressed
Tillage: moldboard plow in spring

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1972			19.8*	84.4
1973			29.0*	84.4
Tile Flow				
1972			9.1* (46.0%)	
1973			14.7* (50.7%)	

*For the periods April-May 1972 and March-July 1973.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)	
	1972	1973
NO_3-N	11.4	30.8
Ortho-P	0.41	0.20
Soluble K	3.21	3.45

4. WEDDING FARM

Site Characteristics

Location: Union County
Area: 4.1 ha
Soil: 75% Blount silt loam, 25% Wetzel silty clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 0.9
Tile spacing (meters): 16.7
Tile flow frequency: intermittent
Sampling method: grab sample
Sampling frequency: daily during April-May 1972 and March-April 1973
Years sampled: 1972-1973

Crop Production Characteristics

Crop: alfalfa
Fertilizer: dairy manure was applied annually at ~20 mt/ha
Tillage: none

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1972			18.8*	84.4
1973			34.0*	84.4
Tile Flow				
1972			1.5* (8.0%)	
1973			8.1* (23.8%)	

*For the periods April-May 1972 and March-April 1973.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)	
	1972	1973
NO_3-N	0.1	1.3
Ortho-P	0.006	0.13
Soluble K	0.48	1.91

5. PLOTS AT HOYTVILLE

Site Characteristics

Location: OARDC Northwestern Branch, Hoytville
Area: 0.04 ha each; 8 plots
Soil: Hoytville clay

Tile Characteristics and Monitoring

Tile depth (meters): 0.9
Tile spacing (meters): 15.2
Tile flow frequency: intermittent
Sampling method: automatic sampler
Sampling frequency: continuous throughout the year
Years sampled: 1975-1977

Crop Production Characteristics

Crop: soybeans
Fertilizer: small amount of row fertilizer each year at planting; 34 and 83 kg/ha of P and K were broadcast applied in Fall of 1975 and again in 1976
Tillage: several different tillage systems were used on the plots including fall moldboard plow, chisel plow, and no-till; there were no differences between treatments and mean values of all eight plots are presented

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1975			79.4*	81
1976			67.9	81
1977			94.4	81
Tile Flow				
1975			24.3* (30.6%)	
1976			22.8 (33.6%)	
1977			25.7 (27.2%)	

*For the period April-December.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)		
	1975	1976	1977
NH_4-N	5.8	0.6	0.2
NO_3-N	17.1	11.9	23.0
TKN*	19.6	13.3	2.6
Ortho-P	0.03	0.10	0.26
Total P	0.12	0.45	0.82

*In 1975 and 1976, total N was measured instead of TKN. Total N includes NO_3-N.

6. HEISLER FARM

Site Characteristics

Location: Defiance County
Area: 0.9 ha
Soil: Blount loam

Tile Characteristics and Monitoring

Tile depth (meters): 0.9
Tile spacing (meters): 15.2
Tile flow frequency: intermittent
Sampling method: automatic sampler
Sampling frequency: continuous
Years sampled: 1975-1977

Crop Production Characteristics

Crop: soybeans
Fertilizer: 112 kg/ha of 4-10-10 at planting in 1976 only
Tillage: fall moldboard plow; spring discing

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1975			43.8*	84.6
1976			66.1	84.6
1977			34.5*	84.6
Tile Flow				
1975			5.8* (13.2%)	
1976			11.5 (17.4%)	
1977			9.3* (27.0%)	

*Monitoring began in July 1975 and terminated at the end of May 1977. Precipitation and flow are for those periods only.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)		
	1975	1976	1977
NH_4-N	0.7	0.1	0.1
NO_3-N	7.2	9.6	11.3
TKN*	9.1	11.4	5.3
Ortho-P	0.03	0.09	0.03
Total P	0.10	0.39	0.31

*In 1975 and 1976, total N was measured instead of TKN. Total N includes NO_3-N.

7. SPEISER FARM

Site Characteristics

Location: Defiance County
Area: 0.09 ha
Soil: Paulding clay

Tile Characteristics and Monitoring

Tile depth (meters): 0.9
Tile spacing (meters): 15.2
Tile flow frequency: intermittent
Sampling method: automatic sampler
Sampling frequency: continuous
Years sampled: 1975-1977

Crop Production Characteristics

Crop: soybeans
Fertilizer: none
Tillage: fall moldboard plow

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1975			52.1*	84.6
1976			61.5	84.6
1977			35.8*	84.6
Tile Flow				
1975			0.9* (1.7%)	
1976			2.8 (4.6%)	
1977			0.0* (0.0%)	

*Monitoring began in July 1975 and terminated at the end of May 1977. Precipitation and flow are for those periods only.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)		
	1975	1976	1977
NH_4-N	0.1	0.1	†
NO_3-N	0.4	9.2	
TKN*	0.9	10.1	
Ortho-P	0.01	0.01	
Total P	0.12	0.09	

*In 1975 and 1976, total N was measured instead of TKN. Total N includes NO_3-N.
†There was no tile flow in 1977.

8. ROHRS FARM

Site Characteristics

Location: Defiance County
Area: 0.09 ha
Soil: Lenawee sandy clay loam

Tile Characteristics and Monitoring

Tile depth (meters): 0.9
Tile spacing (meters): 15.2
Tile flow frequency: intermittent
Sampling method: automatic sampler
Sampling frequency: continuous
Years sampled: 1975-1977

Crop Production Characteristics

Crop: soybeans
Fertilizer: 146 kg/ha 0-23-30 applied in the row at planting in 1975 and 1976
Tillage: fall moldboard plow; disced in the spring

Precipitation and Tile Flow (cm)

	Snow	Rain	Annual	Long-term
Precipitation				
1975			42.6*	84.6
1976			59.2	84.6
1977			32.1	84.6
Tile Flow				
1975			10.2* (23.9%)	
1976			9.0 (15.2%)	
1977			7.0* (21.8%)	

*Monitoring began in July 1975 and terminated at the end of May 1977. Precipitation and flow are for those periods only.

Nutrient Losses in Tile Flow

	Annual Loss (kg/ha)		
	1975	1976	1977
NH_4-N	0.6	0.4	0.1
NO_3-N	10.9	5.7	8.4
TKN*	9.2	7.8	4.7
Ortho-P	0.04	0.08	0.09
Total P	0.94	0.24	0.49

*In 1975 and 1976, total N was measured instead of TKN. Total N includes NO_3-N.

TABLE 5.—Summary of Ohio Tile Drainage Data.

Site	Area	Year	Precipitation†	Flow†	Annual Loss NH$_4$-N	NO$_3$-N	TKN	Ortho-P	Total P	Soluble K
	ha		cm		kg/ha					
Castalia										
No-till	0.074	1969	106.2	33.1		32.3		1.27		6.12
		1970	81.8	9.0		28.6		0.58	0.74	5.50
		1971	68.8	10.2		10.7		0.29	0.78	3.29
Fall Plow	0.074	1969	106.2	37.5		31.2		1.37		4.13
		1970	81.8	16.0		25.5		0.19	0.80	4.74
		1971	68.8	8.8		18.9		0.07	0.40	0.92
Dellinger Farm	2.9	1972	34.3	21.8		36.5		0.46		1.41
		1973	49.3	32.5		45.6		0.20		2.21
Durban Farm	3.0	1972	19.8	9.1		11.4		0.41		3.21
		1973	29.0	14.7		30.8		0.20		3.45
Wedding Farm	4.1	1972	18.8	1.5		0.1		0.01		0.48
		1973	34.0	8.1		1.3		0.13		1.91
Hoytville	0.004	1975	79.4	24.3	5.8	17.1	19.6*	0.03	0.12	
		1976	67.9	22.8	0.6	11.9	13.3*	0.10	0.45	
		1977	94.4	25.7	0.2	23.0	2.6	0.26	0.82	
Heisler Farm	0.9	1975	43.8	5.8	0.7	7.2	9.1*	0.03	0.10	
		1976	66.1	11.5	0.1	9.6	11.4*	0.09	0.39	
		1977	34.5	9.3	0.1	11.3	5.3	0.03	0.31	
Speiser Farm	0.09	1975	52.1	0.9	0.1	0.4	0.9	0.01	0.12	
		1976	61.5	2.8	0.1	9.2	10.1	0.01	0.09	
		1977	35.8	0.0						
Rohrs Farm	0.09	1975	42.6	10.2	0.6	10.9	9.2*	0.04	0.94	
		1976	59.2	9.0	0.4	5.7	7.8*	0.08	0.27	
		1977	32.1	7.0	0.1	8.4	4.7	0.09	0.49	
Mean‡			75.7	16.9	0.3	18.8		0.39	0.53	3.11

*In 1975 and 1976, total N was measured instead of TKN. Total N includes NO$_3$-N.
†Some precipitation and tile flow data are for partial years. See data for individual systems for details.
‡Means are only for those systems and years where data for the whole year were available.